UNIVERSITÉ DE MONTRÉAL

CENTRE DE RECHERCHE SUR LES TRANSPORTS

CASE POSTALE 6128, SUCCURSALE A, MONTRÉAL, QUÉBEC, H3C 3J7

ANALYSIS OF REGULATION EFFECTS IN THE TRUCKING INDUSTRY: A TECHNOLOGICAL APPROACH*

by

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* Paper presented at the second seminar on "Freight Transport Planning and Logistics", Bressanone, Italy, July 6-10, 1987.

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I would like to thank F.C.A.R. – Québec (Action-concertée/Transport des marchandises) and Transport Canada for their financial support. I am also indebted to Georges Dionne and Marcel Monette for their helpful comments.

Cette étude a été publiée grâce à une subvention du fonds F.C.A.R. pour l'aide et le soutien à la recherche.

Université de Montréal
Centre de recherche sur les transports - Publication #521
May 1987

Dépôt légal - 2e trimestre 1987

ABSTRACT

This paper presents the methodology used to analyze the technology of the trucking industry and also its theoretical background. Thus, after having presented the theoretical background, the methodology itself and its particular application to the trucking industry are described. Also, in this paper, we present three possible uses of this methodolody: the analyses of returns to scale, productivity growth, and beneficiaries of regulation.

Keywords: regulation, trucking, technology.

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RÉSUMÉ

Dans cet article, nous présentons la méthodologie, de même que ses fondements théoriques, nécessaire à l'analyse de la structure de la technologie dans l'industrie du transport par camion. Une fois la structure de la technologie connue, plusieurs aspects intéressants concernant le débat actuel sur la réglementation peuvent être analysés. Dans cet article, trois aspects en particulier ont été traités : les rendements d'échelles, la croissance de la productivité et les bénéficiaires de la réglementation.

Mots-clés : réglementation, camionnage, technologie.

1. INTRODUCTION

In recent years, deregulation in the transport industries has been an important issue in North America. The U.S. airline industry experienced large scale deregulation in 1978 and, since 1980, the trucking industry operates in a more competitive environment. In Canada, large scale deregulation of the transport industries has not yet been implemented. However, since 1984, a certain political will toward deregulation has been observed at the provincial and federal levels of government (Axworthy, 1984, and Transport Canada, 1985).

Deregulation usually means the removal of the obligation by a transportation firm to own a permit in order to operate in a given territory. This permit, granted by a transport commission, fixes the rates, the network and also the frequency of services for a particular carrier. For example, in the province of Québec, trucking firms must obtain a permit from the Québec Transport Commission to carry goods across the province. This permit fixes the rates the carrier may charge, the kind of goods he may carry, the routes he may use, the markets he may serve, as well as the frequency of service he must offer. In a deregulate environment, carriers are free to charge the rates they want, carry the goods they want and serve the markets of their choice.

Deregulation in Canada faces opposition by certain influential groups. For example, in the airline industry, opposition to deregulation mainly comes from labour unions, since workers seem to be the main beneficiaries of regulation (Trapani and Olson, 1981). In fact, the absence of rate competition in the Canadian airline industry leads carriers to compete on other grounds, such as quality of services offered (flight frequency, quality of meals, etc.). This kind of competition was leading to a higher use of workers, hence the opposition by labour unions to

deregulation. In the trucking industry, though the main beneficiaries of regulation seem to be the workers in the industry (Moore, 1978, and Kim, 1984), opposition to deregulation comes especially from the owners of trucking firms. They maintain that the trucking industry is characterized by an increasing returns to scale technology and that deregulation would mean cut-throat competition by the large carriers, leading to the monopolization of the industry.

On the other hand, many studies investigating the technology of trucking firms concluded, in spite of ambiguous results, the absence of increasing returns to scale. Some authors came to the conclusion that the trucking industry is characterized by weakly decreasing returns to scale when a proper specification of the cost function is used (Spady and Friedlaender, 1978, 1981).

The main purpose of this paper is to present the methodology used to analyze the technology of the trucking industry and also its theoretical background.[1] This methodology is particularly useful when investigating the questions of returns to scale, beneficiaries of regulation and productivity growth in the trucking industry. In the first section of this paper, the theoretical background of the methodology is presented. In the second section, the methodology itself and its particular application to the trucking industry are described. The third section is devoted to the possible use of this methodology regarding returns to scale, productivity growth, and the beneficiaries of regulation. Although this paper concentrates primarily on the application of the methodology to the trucking industry, we must emphasize the fact that it can be used for other regulated industries such as the airline industry, electric utilities and the rail industry (Spady and Friedlaender, 1981; Caves, Christensen and Tretheway, 1984; Christensen and Greene, 1976).

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[1] For a review of methodologies used for the airline industry, see Dionne and Gagné (1986).

2. THEORETICAL BACKGROUND

2.1 Primal approach to the analysis of technology

A trucking firm produces various outputs $(y_1, y_2, \ldots, y_n)$ from a variety of inputs $(x_1, x_2, \ldots, x_m)$. Therefore, we are looking for a relationship to establish the possible physical combinations of inputs and outputs. The relationship needs not only to represent the possible physical combinations but also the efficient ones. A natural way to represent this relationship is to set out a production (or transformation) function:

$$T(y,x) = 0 \qquad (1)$$

where y is an nx1 vector of outputs;
x is an mx1 vector of inputs;
T a function.

This production function (1) establishes which combination of inputs and outputs are possible and efficient. By efficient, we mean that the production function restricts the set of possible outputs to the vectors of maximum outputs for given vectors of inputs. For example, in figure 1, where x_1 is an input and y_1 an output, both A and B are possible, but only B is efficient, while C is neither efficient nor possible for a given level of input $(\bar{x}_1)$.

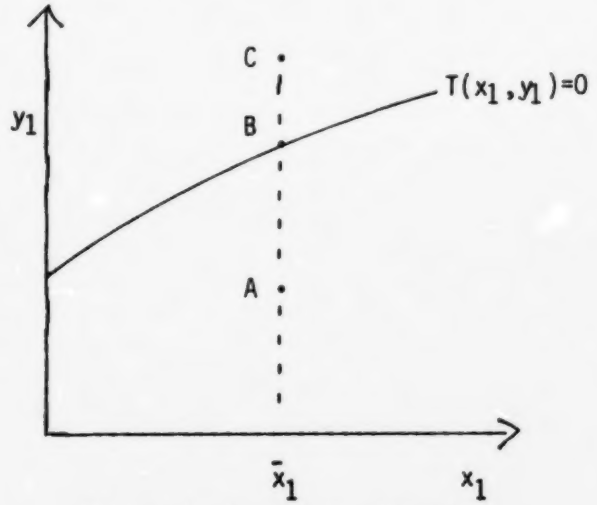

Figure 1: Production function

In order to simplify this, let us suppose that we are using m inputs for the production of only one output

$$y = f(x_1, x_2, \ldots, x_m) \qquad (2)$$

where y is the output (from now on a scalar measure);
$x_1, \ldots, x_m$ are the inputs;
f is a function.

Like production function (1), relation (2) establishes the set $(y, x_1, x_2, \ldots, x_m)$ of possible and efficient combinations of inputs and output. From this production function, we can define the following concepts:

Definition 1 - Constant returns to scale

A technology is characterized by constant returns to scale if the following equality always holds:

$$f(tx_1, tx_2, \ldots, tx_m) = t\, f(x_1, x_2, \ldots, x_m) , \qquad \text{for } t > 1 .$$

In this case, $f(x_1, x_2, \ldots, x_m)$ is a homogeneous function of degree one.

Definition 2 - Increasing returns to scale

A technology is characterized by increasing returns to scale if the following inequality always holds:

$$f(tx_1, tx_2, \ldots, tx_m) > t\, f(x_1, x_2, \ldots, x_m) , \qquad \text{for } t > 1 .$$

Definition 3 - Decreasing returns to scale

A technology is characterized by decreasing returns to scale if the following inequality always holds:

$$f(tx_1, tx_2, \ldots, tx_m) < t\, f(x_1, x_2, \ldots, x_m) , \qquad \text{for } t > 1 .$$

In a regulated industry, the choices the firm faces regarding its production plans are limited. Thus, in the trucking industry, rates are usually fixed by a transport commission, therefore exogenous to the

firm. Also, the firm does not have the freedom to determine its level of output because the permit it holds forces it to respond to the totality of demand in the markets served. Finally, most of the inputs used by a trucking firm are bought or rented in competitive markets where the firm does not have the power to influence the prices of these inputs. Considering these institutional and market constraints, the firm does not have a wide variety of choices regarding its production plans. In most cases, the only choice left to the firm is the choice of inputs that it will be using and a limited choice regarding its output since the firm must request additional permits in order to expand it.

With the help of a simple model, we can formulate the choices faced by the firm subject to the above constraints. Let us consider a case where the firm faces exogenous rates, usually fixed by a transport commission, and bought or rented inputs on competitive markets. In this case, the firm maximizes its profits subject to the technological constraint[1]

$$\begin{aligned} &\text{MAX} && \tilde{p}y - \tilde{w}'x \\ &\text{subject to} && y = f(x). \end{aligned} \tag{3}$$

where $\tilde{p}$ is the exogenous rate;
y is the level of output;
$\tilde{w}$ is an mxl vector of inputs prices;
x is an mxl vector of inputs;
$\sim$ is for exogenous variables.

From the first order conditions of (3), we can derive the supply function of the firm and also its inputs demand functions:

$$y = g(\tilde{p},\tilde{w}) \quad \text{(supply)} \tag{4}$$

$$x_s = h_s(\tilde{p},\tilde{w}) \quad \text{(inputs demand)} \qquad s=1,2,\ldots,m\ . \tag{5}$$

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[1] In numerous cases, the firm cannot respect the equality of this constraint. For example, a regulated trucking firm may faces empty backhauls because its permit does not allow it to carry goods over some directions. We may substitute for this constraint the following one: $f(x) > y$. However, with this new constraint we accept non-efficient, although possible, combinations of inputs.

Hence, from this model we can draw interesting conclusions regarding the deregulation debate in the trucking industry and in other industries as well. Thus, the question of the beneficiaries of regulation could be analyzed with the supply and input demand functions. Moreover, the knowledge of the production function (f(x)) could be very useful in investigating the question of returns to scale.

But, the application of this model cannot take place without going through the econometric estimations of the production function. For example, let us suppose that we do have information (i.e., a sufficient number of observations) about input utilization and output level. From this information and under the hypothesis of a Cobb-Douglas technology, we can estimate the following relationship:

$$y = \alpha_0 + \alpha_1 \ln x_1 + \alpha_2 \ln x_2 + \ldots + \alpha_m \ln x_m + \varepsilon \qquad (6)$$

where $\alpha_0, \alpha_1, \ldots, \alpha_m$ are the parameters of the production function to be estimated;

ε is a disturbance term with zero mean and finite variance.

In general, if there is no correlation between the right-hand side variables of (6) and the disturbance term, the estimation of (6) by ordinary least squares would give unbiased estimates of $\alpha_0, \alpha_1, \ldots, \alpha_m$. Unfortunately, in most cases, there is correlation between the right-hand side variables of (6) and the disturbance term. For instance, suppose that the manager of a firm observes some variables which influence his input choice, but these variables are not observed by the analyst who tries to estimate the production function. The effects of the leftout variables on output are found in the disturbance term. Since the choice of inputs is partly related to these variables, and since the disturbance term is partly a function of these variables, the correlation between the input variables and the disturbance term will be

different from zero, thereby introducing a bias in the estimation of the α's (Varian, 1984). For example, if the manager observes a variation in the quality of some inputs, he modifies the input combination in accordance with this variation. Also, the effect on output level of the quality variation of some inputs (that we do not observe) is taken into account by the disturbance term. Hence the correlation between the explanatory variables and the disturbance term, leading to the invalidity of the estimation.

In real life situations, there are strong reasons to believe that a firm's manager observes some variables ignored by the analyst conducting a study on technology. For this reason, direct estimations of the production function are invalid and an alternative method of analysis must be used. The next section presents an alternative to the above, a method based on the costs minimization problem of the firm.

2.2 Dual approach to the analysis of technology

In this section, instead of considering the problem of profit maximization by the firm, we will considerate the problem of cost minimization.[1] The theorem of duality (Shephard, 1953) allows us to infer the technology of a firm in terms of relations between quantities (the primal problem) or in terms of relations between prices (the dual problem) as long as the firm is cost minimizing. The problem of the firm is now

$$\text{Min} \quad \tilde{w}'x \tag{7}$$

$$\text{subject to} \quad f(x)=\tilde{y} \ .$$

From the first order conditions, we can find the cost function $C=C(\tilde{w},\tilde{y})$, i.e. the minimum cost of producing $\tilde{y}$ with inputs prices $\tilde{w}$.

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[1] The problem of cost minimization is equivalent to the problem of profit maximization.

Applying the theorem of duality, we can infer directly from the cost function, the structure of technology of a firm.

From a theoretical point of view, the cost function has many properties:[1]

Property 1: $C(\tilde{w},\tilde{y})$ is a non-decreasing function in $\tilde{w}$. Therefore, if $\tilde{w}_1 > \tilde{w}_o$ then $C(\tilde{w}_1,\tilde{y}) > C(\tilde{w}_o,\tilde{y})$.

Property 2: $C(\tilde{w},\tilde{y})$ is a homogeneous function of degree 1 in $\tilde{w}$. Therefore, $C(t\tilde{w},\tilde{y}) = t\, C(\tilde{w},\tilde{y})$ for $t>0$.

Property 3: $C(\tilde{w},\tilde{y})$ is a concave function in $\tilde{w}$. Therefore, $C(t\tilde{w}_o+(1-t)\tilde{w}_1, \tilde{y}) \geq t\, C(\tilde{w}_o,\tilde{y}) + (1-t)C(\tilde{w}_1,\tilde{y})$, for $0 \leq t \leq 1$.

Property 4: $C(\tilde{w},\tilde{y})$ is a continuous function in $\tilde{w}$.

Applying Shephard's lemma, from the cost function we can induce the conditional inputs demand functions. Thus, if $C(\tilde{w},\tilde{y})$ is differentiable and if $\tilde{w}_s > 0$ then

$$x_s(\tilde{w},\tilde{y}) = \frac{\partial\, C(\tilde{w},\tilde{y})}{\partial\, \tilde{w}_s} \qquad s=1,2,\ldots,m. \tag{8}$$

where x_s is the conditional demand function of input s.

The four properties of the above cost function involve the following properties for the conditional inputs demand functions:

Property 5: Since $C(\tilde{w},\tilde{y})$ is non-decreasing in $\tilde{w}$, then $\frac{\partial\, C(\tilde{w},\tilde{y})}{\partial\, \tilde{w}_s} = x_s(\tilde{w},\tilde{y}) \geq 0$, for $s=1,2,\ldots,m$.

Property 6: $C(\tilde{w},\tilde{y})$ is homogeneous of degree 1, therefore the first derivatives of the cost function with respect to $\tilde{w}_s$ $(s=1, 2,\ldots,m)$, the conditional input demand functions, are homogeneous of degree 0 in $\tilde{w}$.

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[1] For proofs of those properties, see Varian (1984), chap. 1.

Property 7: Since $C(\tilde{w},\tilde{y})$ is concave in $\tilde{w}$, then the matrix of the second derivatives of the cost function with respect to $\tilde{w}$, the matrix of the first derivatives of the conditional input demand functions, is a negative semi-definite matrix. This implies that the own price-effects are non-positive, therefore

$$\frac{\partial x_s(\tilde{w},\tilde{y})}{\partial \tilde{w}_s} = \frac{\partial^2 C(\tilde{w},\tilde{y})}{\partial \tilde{w}_s^2} \leq 0 , \qquad s=1,\ldots,m$$

since the diagonal elements of a negative semi-definite matrix must be non-positive.

Since the theoretical basis of the cost function has been presented, we may investigate the technology and cost structure of the trucking industry. Let us see firstly how the cost function methodology can be applied to the trucking industry.

3. Toward an estimation of a cost function for the trucking industry

The preceding section has established the foundation of the cost function, the arguments $(\tilde{w},\tilde{y})$ it contains and also its properties. However, we still do not have information about the functional form of this function. For econometric estimations purposes, knowledge of the functional form is necessary. Usually, an approximation of the function is used. In technology and cost structure analyses, a second order approximation of the cost function is used most of the time.[1] This kind of approximation permits the testing of several hypotheses regarding technology, it is flexible, and permits several kinds of returns to scale, homothetic and non-homothetic type of technology and also variable elasticities of substitution between inputs. Finally, such an approximation

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[1] Some authors have used a third order approximation of the cost function for technical change analysis (Friedlaender et Schur Bruce, 1985).

allows the introduction of multi-outputs type of production structure (Spady and Friedlaender, 1976). In this section we will derive a translog approximation of a function and show how it can be used for a cost function in the trucking industry. We will also discuss, at the end of this section, the restrictions to impose to the translog approximation of the cost function in order to take into account the theoretical properties (P1 to P4) presented above.

3.1 Translog approximation of a function

We can approximate a continuous function $h(x)$ with a Taylor series expansion around a point x_o:[1]

$$h(x) = h(x_o) + \sum_{i=1}^{n} h_i(x_o)(x_i - x_o) + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} h_{ij}(x_o)(x_i - x_o)(x_j - x_o) + \text{higher order terms.} \quad (9)$$

$h_i(x_o)$ and $h_{ij}(x_o)$ are respectively the first and second derivatives of $h(x)$ with respect to x evaluate at x_o;

x is the vector $(nx1)$ of the arguments of function h.

Usually, higher order terms are assumed to be very small and then considered to have a zero value. Therefore the approximation of $h(x)$ resume to a second-order approximation of $h(x)$ given by

$$\hat{h}(x) = h(x_o) + \sum_{i=1}^{n} h_i(x_o)(x_i - x_o) + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} h_{ij}(x_o)(x_i - x_o)(x_j - x_o) \quad (10)$$

Consider now the second-order approximation of $\ln g(z)$. We have

$$g(z) = g(e^{\ln z}) \quad (11)$$

$$\ln g(z) = \ln g(e^{\ln z}) = h(\ln z) \quad (12)$$

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[1] Those who are not familiar with the Taylor series expansion are referred to Chiang (1984), chap. 9.

From (10) and assuming that $x = \ln(z)$, we have

$$\hat{h}(x) = \hat{h}(\ln z) = \ln g(z) = h(\ln z_o) + \sum_{i=1}^{n} h_i(\ln z_o)(\ln z_i - \ln z_o) + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} h_{ij}(\ln z_o)(\ln z_i - \ln z_o)(\ln z_j - \ln z_o) \quad (13)$$

If we approximate $\ln g(z)$ around 1, we are falling on the classical translog function, since at $z_o = (1,1,\ldots,1)$ we have $\ln z_o = (0,0,\ldots,0)$, then (13) can be rewritten as

$$\ln g(z) = h(o) + \sum_{i=1}^{n} h_i(o) \ln z_i + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} h_{ij}(o) \ln z_i \ln z_j \quad (14)$$

which is

$$\ln g(z) = \gamma_o + \sum_{i=1}^{n} \gamma_i \ln z_i + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \delta_{ij} \ln z_i \ln z_j \quad (15)$$

if $\gamma_o = h(o)$
$\gamma_i = h_i(o)$
$\delta_{ij} = h_{ij}(o)$

The translog approximation of the cost function as presented by equation (15) could be a poor approximation of the real cost function if its arguments (input prices and outputs) have values far from 1. For this reason, it is more convenient to approximate the cost function around the arithmetic mean of the arguments rather than around 1. Thus, with $\bar{z}_i$ the arithmetic mean of z_i, we approximate the function $\ln g(z)$ around the mean of its arguments by the following relationship:

$$\ln g(z) = \alpha_o + \sum_{i=1}^{n} \alpha_i(\ln z_i - \ln \bar{z}_i) + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij}(\ln z_i - \ln \bar{z}_i)(\ln z_j - \ln \bar{z}_j) \quad (16)$$

3.2 Cost function for the trucking industry[1]

In order to approximate a cost function for the trucking industry, we can already use relationship (16). First, let us separate the z vector in (16) into two different vectors Ψ and w ($z=(\Psi,w)$). The Ψ vector represents the n different outputs produced by the firm, therefore Ψ is a nx1 vector. The w vector represents the m different input prices faced by the firm, therefore w is an mx1 vector. The cost function can therefore be approximated as follows:[2]

$$\begin{aligned} \ln C(\Psi,w) = {} & \alpha_0 + \sum_{i=1}^{n} \alpha_i(\ln \Psi_i - \ln \bar{\Psi}_i) + \sum_{s=1}^{m} \beta_s(\ln w_s - \ln \bar{w}_s) \\ & + \frac{1}{2}\left[\sum_{i=1}^{n}\sum_{j=1}^{n} A_{ij}(\ln \Psi_i - \ln \bar{\Psi}_i)(\ln \Psi_j - \ln \bar{\Psi}_j)\right] \\ & + \frac{1}{2}\left[\sum_{s=1}^{m}\sum_{t=1}^{m} B_{st}(\ln w_s - \ln \bar{w}_s)(\ln w_t - \ln \bar{w}_t)\right] \\ & + \sum_{i=1}^{n}\sum_{s=1}^{m} C_{is}(\ln \Psi_i - \ln \bar{\Psi}_i)(\ln w_s - \ln \bar{w}_s)\Big] \end{aligned} \tag{17}$$

where $C(\Psi,w)$ is the total cost of the firm;

Ψ_i is the measure of output i;

w_s is the input price s;

A_{ij}, B_{st}, C_{ij} are parameters.

Measuring the level of output in transport industries is very difficult. Most of the time, available statistics are limited to

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[1] Although the theoretical background refers to a firm, the analysis of technology is normally undertaken at the industry level because of insufficient data with only one firm. In order to have a sufficient number of observations, one must use a cross-sectional sample of data from several firms. But, in doing this, we are accepting the hypothesis that the parameters of the cost function are the same for all the firms within the sample.

[2] We have already imposed symmetry upon the interaction term ($C_{is}=C_{si}$), though the term 1/2 disappears.

aggregate measures of output for each firm in the industry. In passenger transport services, the most common measure of output used is the number of passenger-kilometer, while in freight transportation services the most common measure is the ton-kilometers carried. However, in both cases, the use of a single measure of aggregate output introduces serious difficulties. For example, in freight transportation, two firms with the same level of output (ton-kilometers) could have incurred different total costs if one firm is specialized in less-than-truckload shipments over short distances while the other is specialized in truckload shipments over long distance. In order to take these characteristics into account, Spady and Friedlaender (1978) have introduced measures of output qualities into the cost function.[1] First, let us fix y_i as a measure of the i'th output and $q_{k\,i}$ as the quality k of the i'th output (i=1,...,n and k=1,...,r). Spady and Friedlaender then use a hedonic function which aggregate the measures of outputs and their qualities:

$$\Psi_i = \Phi_i(y_i, q_i) \quad i=1,2,\ldots,n \tag{18}$$

$$\text{where} \quad q_i = [q_{1i}, q_{2i}, \ldots q_{ri}] .$$

Usually, it seems preferable to assume that the function Φ_i has the following properties (Spady and Friedlaender, 1976, p.42):

i) $\Phi_i(0, q_i) = 0$ and $\Phi_i(y_i, q_i) > 0$ for $y_i > 0$ and $q_i > 0$;

ii) $\Phi_i(y_i, q_i)$ is a homogeneous function of degree 1 in y_i for a given q_i;

iii) $\Phi_i(y_i, q_i)$ is a monotonic function non-decreasing in q_i.

The hedonic function (18) can take many functional forms. In their 1978 paper, Spady and Friedlaender have used the following translog approximation:

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[1] The most common measures used are: average length of haul, average shipment size and average load per truck.

$$\ln \Psi_i = \ln y_i + \sum_{k=1}^{r} G_{ki}(\ln q_{ki} - \ln \bar{q}_{ki}) + \frac{1}{2} \sum_{k=1}^{r} \sum_{\ell=1}^{r} H_{k\ell i}(\ln q_{ki} - \ln \bar{q}_{ki})(\ln q_{\ell i} - \ln \bar{q}_{\ell i}) \tag{19}$$

where G_{ki} and $H_{k\ell i}$ are parameters.

However, in order to keep down the number of estimated parameters, we could use a Cobb-Douglas form of the hedonic function, as Spady and Friedlaender have done in their 1981 paper:

$$\ln \Psi_i = \ln y_i + \sum_{k=1}^{r} L_{ki} \ln q_{ki} \, . \tag{20}$$

where L_{ki} is a parameter.

Both functions (19 and 20) have the desired properties under the assumptions that $G_{ki} > 0$ and $L_{ki} > 0$ for all k, i and ℓ. In imposing restrictions on the parameters of (19) or (20), we can find, as a particular case, the standard translog cost function (17).[1] Furthermore, Spady and Friedlaender (1981) have introduced a more general cost function which takes, as particular cases, the standard and hedonic translog cost functions. Thus, under the hypothesis that a firm minimizes costs (then maximizes profits), we have now the following problem

$$\text{Min} \quad \tilde{w}'x \tag{21}$$

$$\text{subject to} \quad f(x,\tilde{t}) = \Psi$$

where Ψ is the hedonic measure of output;

$\tilde{t}$ is a vector (zx1) characterizing the technological constraints faced by the firm (e.g., size and density of network);

x is the vector of inputs;

$\tilde{w}$ is the vector of inputs prices.

Here, the firm faces input prices and technological constraints and determines its optimal level of hedonic output in order to minimize

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[1] $G_{ki} = 0$ and $H_{k\ell i} = 0$ for (19) and and $L_{ki} = 0$ for (20).

costs. Again, by duality, we know that we can characterize technology in terms of relations between prices. Therefore, from the first order conditions of problem (21), we can obtain the following cost function:

$$C = C(\Psi,w,t) = C(\Phi(y,q),w,t) = C(y,q,w,t) \tag{22}$$

This cost function (the technological cost function) can be approximated by the following translog function:

$$\begin{aligned}
\ln C(\Psi,w,t) = {} & \alpha_o + \sum_{i=1}^{n} \alpha_i(\ln \Psi_i - \ln \bar{\Psi}_i) + \sum_{s=1}^{m} \beta_s(\ln w_s - \ln \bar{w}_s) \\
& + \sum_{p=1}^{z} \gamma_p(\ln t_p - \ln \bar{t}_p) + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} A_{ij}(\ln \Psi_i - \ln \bar{\Psi}_i)(\ln \Psi_j - \ln \bar{\Psi}_j) \\
& + \frac{1}{2} \sum_{s=1}^{m} \sum_{t=1}^{m} B_{st}(\ln w_s - \ln \bar{w}_s)(\ln w_t - \ln \bar{w}_t) \\
& + \frac{1}{2} \sum_{i=1}^{n} \sum_{s=1}^{m} C_{is}(\ln \Psi_i - \ln \bar{\Psi}_i)(\ln w_s - \ln \bar{w}_s) \\
& + \frac{1}{2} \sum_{p=1}^{z} \sum_{v=1}^{z} D_{pv}(\ln t_p - \ln \bar{t}_p)(\ln t_v - \ln \bar{t}_v) \\
& + \sum_{i=1}^{n} \sum_{p=1}^{z} E_{ip}(\ln \Psi_i - \ln \bar{\Psi}_i)(\ln t_p - \ln \bar{t}_p) \\
& + \sum_{s=1}^{m} \sum_{p=1}^{z} F_{sp}(\ln w_s - \ln \bar{w}_s)(\ln t_p - \ln \bar{t}_p)
\end{aligned} \tag{23}$$

with $\Psi_i = \Phi_i(y_i,q_i)$, $E_{ip} = E_{pi}$ and $F_{sp} = F_{ps}$.

The standard translog cost function (17) and the hedonic translog cost function ((17) with (19) or (20)) are nested into the technological translog cost function. Hence, when the proper restrictions are imposed upon the technological cost function, it is easy to derive the standard or the hedonic cost functions. It will then be possible to determine, from tests on restrictions, which form of the cost function (standard,

hedonic or technological) is the better suited for the analysis of the trucking industry technology.

3.3 Properties and restrictions of the translog cost function

From section 2, we know that if the firm has a cost minimization behaviour, the cost function possess four properties. The first property stipulates that the cost function is non-decreasing in w (the input prices), that is : $\frac{\partial C}{\partial w_s} > 0$. However, since $\frac{\partial C}{\partial w_s} = (\frac{\partial \ln C}{\partial \ln w_s}) \frac{C}{w_s}$ and, since $\frac{C}{w_s}$ is always positive, we must verify that $\frac{\partial \ln C}{\partial \ln w_s}$ is nonnegative. $\frac{\partial \ln C}{\partial \ln w_s}$, as we will see in Section 3.4, corresponds to the share in the total costs of factor s. To verify property 1, we must check, for all the observations within the sample, whether the fitted factor shares are nonnegative or not.

Property 2 stipulates that the cost function is a homogeneous function of degree 1 in w (the input prices). Homogeneity of degree 1 implies the following relationship:

$$C(\Psi,\lambda w,t) = \lambda\, C(\Psi,w,t) \tag{24}$$

In logarithmic form (24) becomes

$$\ln C(\Psi,\lambda w,t) = \ln \lambda + \ln C(\Psi,w,t) \tag{25}$$

From (23) and setting $\ln \bar{\Psi}_i = 0$, $\ln \bar{w}_s = 0$ and $\ln \bar{t}_p = 0$, we have

$$\begin{aligned} \ln C(\Psi,\lambda w,t) = {} & \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln \Psi_i + \sum_{s=1}^{m} \beta_s (\ln \lambda + \ln w_s) \\ & + \sum_{p=1}^{z} \gamma_p \ln t_p + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} A_{ij} \ln \Psi_i \ln \Psi_j \\ & + \frac{1}{2} \sum_{s=1}^{m} \sum_{t=1}^{m} B_{st} (\ln \lambda + \ln w_s)(\ln \lambda + \ln w_t) \end{aligned} \tag{26}$$

$$+ \sum_{i=1}^{n} \sum_{s=1}^{m} C_{is} \ln \Psi_i \, (\ln \lambda + \ln w_s)$$

$$+ \frac{1}{2} \sum_{p=1}^{z} \sum_{v=1}^{z} D_{pv} \ln t_p \ln t_v$$

$$+ \sum_{i=1}^{n} \sum_{p=1}^{z} E_{ip} \ln \Psi_i \ln t_p$$

$$+ \sum_{s=1}^{m} \sum_{p=1}^{z} F_{sp} \, (\ln \lambda + \ln w_s) \ln t_p$$

which could be rewritten as

$$\ln C(\Psi, \lambda w, t) = \ln C(\Psi, w, t) + \sum_{s=1}^{m} \beta_s \ln \lambda$$

$$+ \frac{1}{2} \left[\sum_{s=1}^{m} \sum_{t=1}^{m} B_{st} \left[(\ln \lambda)^2 + (\ln \lambda \ln w_t) + (\ln w_s \ln \lambda) \right] \right] \quad (27)$$

$$+ \sum_{i=1}^{n} \sum_{s=1}^{m} C_{is} \ln \Psi_i \ln \lambda + \sum_{p=1}^{z} \sum_{s=1}^{m} F_{sp} \ln t_p \ln \lambda$$

The last two terms of (27) equals zero when $\sum_{s=1}^{m} C_{is} = 0$ and $\sum_{s=1}^{m} F_{sp} = 0$.

Furthermore, we can write the third term of (27) as

$$\frac{1}{2} \left[(\ln \lambda)^2 \sum_{s=1}^{m} \sum_{t=1}^{m} B_{st} + \ln \lambda \sum_{s=1}^{m} \sum_{t=1}^{m} B_{st} \ln w_t + \ln \lambda \sum_{s=1}^{m} \sum_{t=1}^{m} B_{st} \ln w_s \right] \quad (28)$$

Equation (28) equal zero when

$$\sum_{t=1}^{m} B_{st} = 0 \qquad s=1,\ldots,m \quad (29)$$

$$\sum_{s=1}^{m} B_{st} = 0 \qquad t=1,\ldots,m \quad (30)$$

Moreover, since the B matrix is symmetric (by the rule of derivatives) we have $\sum_{s=1}^{m} B_{st} = \sum_{t=1}^{n} B_{st}$. This implies

$$\sum_{t=1}^{m} \sum_{t=1}^{m} B_{st} = 0 \qquad (31)$$

Finally, homogeneity of degree 1 implies this last restriction

$$\sum_{s=1}^{m} \beta_s = 1 \qquad (32)$$

To summarize, homogeneity of degree 1 of the translog cost function implies the following restrictions:

i) $\sum_{s=1}^{m} \beta_s = 1$

ii) $\sum_{s=1}^{m} B_{st} = 0 \qquad t=1,2,\ldots,m$

iii) $\sum_{s=1}^{m} C_{is} = 0 \qquad i=1,2,\ldots,n$

iv) $\sum_{s=1}^{m} F_{sp} = 0 \qquad p=1,2,\ldots,z$

Moreover, by symmetry, we have

v) $B_{st} = B_{ts}$

vi) $A_{ij} = A_{ji}$

vii) $D_{pv} = D_{vp}$

Finally, to insure concavity of the cost function, the Hessian matrix of this function (the matrix of the second derivatives of the cost function with respect to w (hereafter the H matrix)) must be a negative semi-definite matrix. A sufficient condition for negative semi-definiteness is that the signs of the principal minors of the H matrix must alternate with the first one being negative.

Unfortunately, we cannot use the Hessian matrix of the translog cost function, the B matrix (which contains the B_{st} parameters), since the B_{st} parameters are related to the logarithmic value of the cost function. In order to derive the true Hessian matrix, we must translate the Hessian matrix of the translog cost function into the Hessian matrix of the cost function. This is done in the Appendix.

3.4 Econometric estimation of a cost function

In Section 2, we saw that when the firm is minimizing costs, we could infer from Shephard's lemma the conditional input demand functions

$$\frac{\partial C(\Psi,w,t)}{\partial w_s} = x_s \qquad s=1,2,\ldots,m \qquad (34)$$

Then

$$\frac{\partial \ln C(\Psi,w,t)}{\partial \ln w_s} = \frac{\partial C(\Psi,w,t)}{\partial w_s}\,\frac{w_s}{C} = \frac{x_s\, w_s}{C} \qquad s=1,2,\ldots,m\,. \qquad (35)$$

Applying (35) to the translog cost function (23) we obtain the input share equations

$$\frac{w_s x_s}{C} = \beta_s + \sum_{t=1}^{m} B_{st}(\ln w_t - \ln \bar{w}_t) + \sum_{i=1}^{n} C_{is}(\ln \Psi_i - \ln \bar{\Psi}_i) + \sum_{p=1}^{z} F_{sp}(\ln t_p - \ln \bar{t}_p) \qquad s=1,2,\ldots,m\,. \qquad (36)$$

To estimate (23) and (36), we must add to each of these equations a disturbance term. Let us call them ε_c and ε_s (s=1,2,...,m). One may think that ε_c and ε_s (s=1,2,...,m) are correlated for a single observa

tion (a firm). Therefore, in order to take into account this correlation, we may use a simultaneous approach in the estimation of (23) and (36).[1] However, since $\sum_{s=1}^{m} \frac{x_s w_s}{C} = 1$ we have $\sum_{s=1}^{m} \varepsilon_s = 0$. Therefore, the variance-covariance matrix of the disturbance term (Ω) is a singular matrix and, in order to avoid this singularity, we should drop an input share equation.[2]

4. SOME POSSIBLE USES OF THE TRANSLOG COST FUNCTION REGARDING REGULATION ANALYSIS

4.1 Returns to scale

From estimates of the translog cost function, many interesting analyses concerning the deregulation debate can be done. One of them is the analysis of returns to scale. The question of interest here is to determine if the trucking industry operates with increasing returns to scale. The opponents to deregulation in the trucking industry maintain that this industry is characterized by increasing returns to scale technology and, therefore, that deregulation will allow large carriers to practice low prices competition in order to eliminate small carriers, leading to the monopolization of the industry.

In Section 2, we defined returns to scale in terms of relations between input quantities. We saw that when an increase in inputs leads to a more than proportionate increase in outputs, the technology is said to be characterized by increasing returns to scale. In terms of rela-

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[1] It seems that the simultaneous approach improves the results (Christensen and Greene, 1976).

[2] Barten (1969) has shown that the results are independent of the input share equation dropped.

tions between prices (the dual approach) we can do a similar analysis. Thus, we will say that a technology is characterized by increasing (decreasing) returns to scale when an increase in output will lead to a less (more) than proportionate increase in costs. Moreover, we will have constant returns to scale when an increase in output will lead to a proportionate increase in costs. From an elasticity point of view

i) if $\varepsilon_{C\Psi} < 1$, the technology is characterized by increasing returns to scale;

ii) if $\varepsilon_{C\Psi} = 1$, the technology is characterized by constant returns to scale;

iii) if $\varepsilon_{C\Psi} > 1$, the technology is characterized by decreasing returns to scale.

where $\varepsilon_{C\Psi} = \frac{\partial \ln C(\Psi, w, t)}{\partial \ln \Psi}$, the elasticity of costs with respect to output.[1] In terms of the translog cost function (23), the elasticity of costs with respect to output is

$$\varepsilon_{C\Psi} = \alpha_{\Psi} + A_{\Psi\Psi}(\ln \Psi - \ln \bar{\Psi}) + \sum_{s=1}^{m} C_{\Psi s}(\ln w_s - \ln \bar{w}_s) + \sum_{p=1}^{z} \varepsilon_{\Psi p}(\ln t_p - \ln \bar{t}_p) \tag{37}$$

Thus, with average output, average input prices and average technological constraints, returns to scale are simply defined by the parameter α_{Ψ}. We cannot globally characterize returns to scale from the parameter α_{Ψ} since it only defines returns to scale for the average firm. For this

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[1] From now on we will consider that there is only one hedonic output (n=1).

reason, it is often more interesting to draw results concerning returns to scale from the average cost function. From the average cost point of view, returns to scale are said to be increasing (decreasing or constant) when average cost decreases (increases or stays constant) with respect to output, where average cost is defined as the ratio of total costs over output

$$AC = \frac{C(\Psi,w,t)}{\Psi} \quad . \tag{38}$$

Using logarithmics, (38) can be written as

$$\ln AC = \ln C(\Psi,w,t) - \ln \Psi \quad . \tag{39}$$

We can thus define returns to scale in terms of the average cost function as

i) $\frac{\partial \ln AC}{\partial \ln \Psi} < 0$, increasing returns to scale;

ii) $\frac{\partial \ln AC}{\partial \ln \Psi} = 0$, constant returns to scale;

iii) $\frac{\partial \ln AC}{\partial \ln \Psi} > 0$, increasing returns to scale.

From (39) we obtain the following relationship for $\frac{\partial \ln AC}{\partial \ln \Psi}$

$$\frac{\partial \ln AC}{\partial \ln \Psi} = \frac{\partial \ln C(\Psi,w,t)}{\partial \ln \Psi} - 1 = \varepsilon_{C\Psi} - 1 \tag{40}$$

Therefore, for average input prices and technological constraints we have

$$\frac{\partial \ln AC}{\partial \ln \Psi} = (\alpha_{\Psi} - 1) + A_{\Psi\Psi}(\ln \Psi - \ln \bar{\Psi}) \tag{41}$$

The shape of the average cost curve depend on the values of parameters

α_Ψ and $A_{\Psi\Psi}$. Table 1 presents all possible outcomes regarding the shape of the average cost curve for different values of α_Ψ and $A_{\Psi\Psi}$.

Table 1: Possible shapes of the average cost curve[1]

	$A_{\Psi\Psi}>0$			$A_{\Psi\Psi}=0$		
	$\alpha_\Psi<1$	$\alpha_\Psi=1$	$\alpha_\Psi>1$	$\alpha_\Psi<1$	$\alpha_\Psi=1$	$\alpha_\Psi>1$
Shape of the curve	U shape	U shape	U shape	exponentially decreasing	constant	exponentially increasing
Minimum at	$\Psi>\bar{\Psi}$	$\Psi=\bar{\Psi}$	$\Psi<\bar{\Psi}$	-	-	-

For example, in Figure 2 we present an average cost curve with $A_{\Psi\Psi}>0$ and $\alpha_\Psi=1$. In that case, for $\Psi<\bar{\Psi}$ firms operate at increasing returns to scale, while at $\Psi=\bar{\Psi}$ firms operate at constant returns to scale and at decreasing returns to scale for $\Psi>\bar{\Psi}$. From this specific example, we could conclude that smaller firms (those for which $\Psi<\bar{\Psi}$) operates at increasing returns to scale, while large firms operate at decreasing returns to scale. We can also see from this example why it is not possible to globally characterize returns to scale, but only over certain ranges of output.

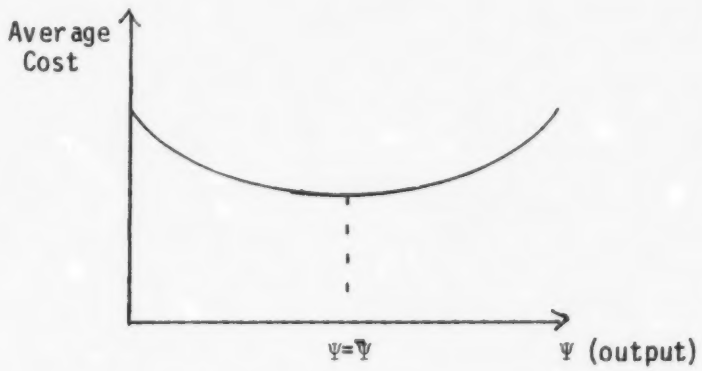

Figure 2: Average cost curve with $A_{\Psi\Psi}>0$ and $\alpha_\Psi=1$

[1] The case where $A_{\Psi\Psi}<0$ is irrelevant since it has no economic significance.

4.2 Productivity growth

It is well recognized in the economic literature that regulation procures benefits for certain groups or individual agents. Usually, three major groups can be identified as beneficiaries of regulation: the owners of stocks, the owners of production factors and the consumers. In the transportation literature, mainly the airline industry and the trucking industry, most of the authors agree on the fact that regulation confers benefits to the owners of factors.[1] For example, Trapani and Olson (1981) have shown that regulation of the airline industry in the U.S. benefited aircraft manufacturers, fuel suppliers and other inputs suppliers. In the trucking industry, Moore (1978) for the U.S. and, later, Kim (1984) for Canada, have shown that regulation in this industry has benefited labour suppliers. In both cases, benefits take the form of over-utilization of inputs in producing a given level of output.

Since regulation seems to imply a sub-optimal utilization of resources, productivity should be lower under regulation than it would have been in its absence. Hence, in comparing productivity trends in an industry which experiences regulatory changes or in comparing productivity trends of different segments of an industry facing different regulatory environments, we should be able to determine the effects of regulation on the productivity of transportation firms.

In order to measure productivity growth in the trucking industry, we can use a modified version of the above translog cost function. Following Friedlaender and Schur Bruce (1985), let us first assume that the cost function has the following form:

$$C = C(\Psi, w, t, T) \qquad (42)$$

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[1] See the next section for more details about the beneficiaries of regulation.

where C, Ψ, w, t have their preceding meanings and T represents time.

In order to measure productivity growth, we introduce time into the translog cost function. In doing so, we use a truncated third-order translog approximation of the cost function (42) in which we drop the third-order terms which do not involve the time variable. Therefore, our translog cost function now takes the following form:[1]

$$\begin{aligned}
\ln C(\Psi,w,t,T) = \alpha_o &+ \sum_{i=1}^{n} \alpha_i(\ln \Psi_i - \ln \bar{\Psi}_i) + \sum_{s=1}^{m} \beta_s(\ln w_s - \ln \bar{w}_s) \\
&+ \sum_{p=1}^{z} \gamma_p(\ln t_p - \ln \bar{t}_p) + \delta_t T \\
&+ \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} A_{ij}(\ln \Psi_i - \ln \bar{\Psi}_j)(\ln \Psi_j - \ln \bar{\Psi}_j) \\
&+ \frac{1}{2} \sum_{s=1}^{m} \sum_{t=1}^{m} B_{st}(\ln w_s - \ln \bar{w}_s)(\ln w_t - \ln \bar{w}_t) \\
&+ \sum_{i=1}^{n} \sum_{s=1}^{m} C_{is}(\ln \Psi_i - \ln \bar{\Psi}_i)(\ln w_s - \ln \bar{w}_s) \\
&+ \frac{1}{2} \sum_{p=1}^{z} \sum_{v=1}^{z} D_{pv}(\ln t_p - \ln \bar{t}_p)(\ln t_v - \ln \bar{t}_v) \\
&+ \sum_{i=1}^{n} \sum_{p=1}^{z} E_{ip}(\ln \Psi_i - \ln \bar{\Psi}_i)(\ln t_p - \ln \bar{t}_p) \qquad (43) \\
&+ \sum_{s=1}^{m} \sum_{p=1}^{z} F_{sp}(\ln w_s - \ln \bar{w}_s)(\ln t_p - \ln \bar{t}_p) \\
&+ \sum_{s=1}^{m} G_{sT}(\ln w_s - \ln \bar{w}_s)T + \frac{1}{2}[J_{tt} T^2]
\end{aligned}$$

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[1] The usual symmetry and homogeneity conditions must be imposed in order to ensure cost minimization.

$$+ \sum_{i=1}^{n} H_{iT}(\ln \Psi_i - \ln \bar{\Psi}_i)T$$

$$+ \sum_{p=1}^{z} I_{pT}(\ln t_p - \ln \bar{t}_p)T$$

$$+ \frac{1}{2} \sum_{s=1}^{m} \sum_{t=1}^{m} K_{stT}(\ln w_s - \ln \bar{w}_s)(\ln w_t - \ln \bar{w}_t)T$$

$$+ \sum_{s=1}^{m} \sum_{p=1}^{z} L_{spT}(\ln w_s - \ln \bar{w}_s)(\ln t_p - \ln \bar{t}_p)T$$

$$+ \sum_{s=1}^{m} \sum_{i=1}^{n} M_{siT}(\ln w_s - \ln \bar{w}_s)(\ln \Psi_i - \ln \bar{\Psi}_i)T$$

$$+ \frac{1}{2} \sum_{p=1}^{z} \sum_{v=1}^{z} N_{pvT}(\ln t_p - \ln \bar{t}_p)(\ln t_v - \ln \bar{t}_v)T$$

$$+ \sum_{p=1}^{z} \sum_{i=1}^{n} O_{piT}(\ln t_p - \ln \bar{t}_p)(\ln \Psi_i - \ln \bar{\Psi}_i)T$$

$$+ \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} P_{ijT}(\ln \Psi_i - \ln \bar{\Psi}_i)(\ln \Psi_j - \ln \bar{\Psi}_j)T$$

where $\Psi_i = \Phi(y_i, q_i)$.

Differentiating (43) with respect to time gives us an expression that can be divided into pure productivity effect, input effect, output effect, and technological constraints effect

$$\frac{\partial \ln C}{\partial T} = \delta_t + J_{tt}T + \sum_{i=1}^{n} H_{iT}(\ln \Psi_i - \ln \bar{\Psi}_i) + \sum_{s=1}^{m} G_{sT}(\ln w_s + \ln \bar{w}_s)$$

$$+ \sum_{p=1}^{z} I_{pT}(\ln t_p - \ln \bar{t}_p) + \frac{1}{2} \sum_{s=1}^{m} \sum_{t=1}^{m} K_{stT}(\ln w_s - \ln \bar{w}_s)(\ln w_t - \ln \bar{w}_t)$$

$$+ \sum_{s=1}^{m} \sum_{p=1}^{z} L_{spT}(\ln w_s - \ln \bar{w}_s)(\ln t_p - \ln \bar{t}_p)$$

$$+ \sum_{s=1}^{m} \sum_{i=1}^{n} M_{siT}(\ln w_s - \ln \bar{w}_s)(\ln \Psi_i - \ln \bar{\Psi}_i) \tag{44}$$

$$+ \frac{1}{2} \sum_{p=1}^{z} \sum_{v=1}^{z} N_{pvT}(\ln t_p - \ln \bar{t}_p)(\ln t_v - \ln \bar{t}_v)$$

$$+ \sum_{p=1}^{z} \sum_{i=1}^{n} O_{piT}(\ln t_p - \ln \bar{t}_p)(\ln \Psi_i - \ln \bar{\Psi}_i)$$

$$+ \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} P_{ijT}(\ln \Psi_i - \ln \bar{\Psi}_i)(\ln \Psi_j - \ln \bar{\Psi}_j)$$

The pure productivity effect is given by the change in costs with respect to time at $w=\bar{w}$, $t=\bar{t}$ and $\Psi=\bar{\Psi}$, that is

$$\frac{\partial \ln C}{\partial T} = \delta_t + J_{tt}T \tag{45}$$

The input effect (46), the output effect (47) and the technological constraints effect (48) are obtained by differentiating (44) with respect to $\ln w_s$, $\ln \Psi_i$ and $\ln t_p$

$$\frac{\partial^2 \ln C}{\partial T \, \partial \ln w_s} = G_{sT} + \frac{1}{2} \sum_{t=1}^{m} K_{stT}(\ln w_t - \ln \bar{w}_t) + \sum_{p=1}^{z} L_{spT}(\ln t_p + \ln \bar{t}_p)$$

$$+ \sum_{i=1}^{n} M_{siT}(\ln \Psi_i - \ln \bar{\Psi}_i) \tag{46}$$

$$\frac{\partial^2 \ln C}{\partial T \, \partial \ln \Psi_i} = H_{iT} + \sum_{s=1}^{m} M_{siT}(\ln w_s - \ln \bar{w}_s) + \sum_{p=1}^{z} O_{piT}(\ln t_p - \ln \bar{t}_p)$$

$$+ \frac{1}{2} \sum_{j=1}^{n} P_{ijT}(\ln \Psi_j - \ln \bar{\Psi}_j) \tag{47}$$

$$\frac{\partial^2 \ln C}{\partial T \, \partial \ln t_p} = I_{pT} + \sum_{s=1}^{m} L_{spT}(\ln w_s - \ln \bar{w}_s) + \frac{1}{2} \sum_{v=1}^{z} N_{pvT}(\ln t_v + \ln \bar{t}_v)$$

$$+ \sum_{i=1}^{n} O_{piT}(\ln \Psi_i - \ln \bar{\Psi}_i) \tag{48}$$

The expressions (46), (47) and (48) measure the effect of a change in input prices, output or technological constraints upon the rate of change of costs, while expression (45) measures the residual rate of change in costs not explained by changes in input prices, output or technological constraints. This residual effect is associated to productivity.

For regulation analysis purpose, it is the productivity effect (45) that matters. From econometric estimates of the time augmented translog cost function (43), we can induce productivity growth by evaluating for each time period (T=1,2,...,N) the value of $\delta+J_{tt}T$. Then, by comparing productivity effect upon costs obtained by this method to regulatory changes, we should be able to determine the effect of regulation (or regulatory change) on the productivity of trucking firms.

4.3 Beneficiaries of regulation

Government regulation of many industries exist mainly to protect the interests of consumers. However, some authors (Stigler, 1971; Peltzman, 1976) argue that regulation is often undertaken in response to demand by special interest groups and that it serves the interests of the most powerful groups. Therefore, if the government decides to regulate an economic activity where the consumers cannot exercise a certain power, the effects of regulation may not benefit them. In this case, regulation will not achieve its goal.

At a relatively aggregate level, three major groups can be identified as beneficiaries of regulation: the owners of factors of production, the owners of stocks, and the consumers. In the trucking industry, many studies conclude that the regulatory regime leads to fares higher than those corresponding to the absence of regulation (see for example Sloss, 1970; Maister, 1978; McLachlan, 1972). However, it seems that higher fares do not necessarily mean higher profits. Rather, it is

possible that regulation induces over-utilization of the factors of production and thus higher fares.

In investigating this hypothesis, Moore (1978) found that "three-quarters or more of the cost to shippers and ultimately to consumers of trucking regulation take the form of income transfers to labor and capital involved in trucking" (p. 342).

Assuming that the Canadian trucking regulatory regime, in imposing route structure (network), fares, etc., leads to a sub-optimal production structure, Kim (1984) introduced "conditions induced by the regulatory regime that directly affect the production technology and consequently the costs of producing regulated trucking services" (p. 228). Regulation can affect the production structure (or technology) of the trucking firms in many ways. Empty backhauls, excess circuitry, under-utilization of capacity (because of the restrictions on the type of commodities that may be hauled) are some of the consequences of a regulatory regime. In order to take into account the effects of a regulatory regime on the production structure of the carriers, Kim used what he called a vector of regulatory-induced technological conditions (our technological constraints). These regulatory-induced conditions are the average length of haul (H), the average shipment size (S), and the level of capacity utilization (CU). All these variables were proxies for taking into account the effects of regulation on the production structure of the carriers. The author assumed that in the presence of regulation, H, S and CU are lower than they would be otherwise.

The methodology used by Kim in order to determine if the factors of production benefited from regulation, start from the estimates of the translog cost function and the corresponding factor share equations. From these estimates, it is possible to evaluate the elasticity of the

demand for a factor (say s) with respect to a technological constraint (say p), that is:[1]

$$\Theta_{sp} = \gamma_p + \frac{F_{sp}}{\beta_s} \tag{49}$$

where Θ_{sp} is the elasticity of demand for factor s with respect to technological constraint p;

γ_p is the parameter of the linear term t_p in the cost function;

F_{sp} is the parameter of the interaction term (w_s, t_p) in the cost function;

β_s is the fitted factor share evaluated at $w=\bar{w}$, $\Psi=\bar{\Psi}$ and $t=\bar{t}$.

From these evaluations of Θ_{sp} (s=1,...,m, and p=1,...,z) one can determine if a technological constraint has an effect upon the demand for inputs and, knowing that regulation affects the technological constraints, one can determine whether or not inputs benefit from regulation. Moreover, this method allows the determination of which inputs benefit from regulation and which do not.

The only weakness of this methodology is that it <u>assumes</u> that regulation negatively affects the technological constraints. To our knowledge, no author has yet developed a methodology to measure the impact of regulation upon the technological constraints. A complete analysis of the beneficiaries of regulation would have to take place in a two-stage procedure: the first stage determining the effect of regulation on technological constraints and the second measuring (with relation (49)) the effect of technological constraints on factors demand.

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[1] See Appendix for a derivation of relation (49).

5. CONCLUSION

The aim of this paper was to present a procedure for the investigation of trucking technology. From a theoretical model of costs minimization, we have introduced the translog cost function and show how it can be used to analyze the technology in the trucking industry. Also, in this paper, we have made the link between technology analysis and economic regulation. In this regard, we have shown how to use technology analysis in order to investigate the questions of returns to scale, productivity growth, and the beneficiaries of regulation. However, the methodology itself is not free from criticisms. The main problem is that the translog cost function is only an approximation of the true underlying cost function. But, without any knowledge of the functional form of the cost function, the use of a second or third-order Taylor series expansion seems to be a reasonable compromise. Finally, in using a translog function, we are imposing the logarithmic form to the cost function. Instead of logarithms, Box-Cox transformations of the variables could be used. These transformations could improve the econometric results without imposing an a priori functional form.

APPENDIX

1. Translation of the Hessian matrix of the translog cost function into the Hessian matrix of the cost function

We may state the first derivative of the cost function as follows:

$$\frac{\partial C}{\partial w_s} = \frac{\partial \ln C}{\partial \ln w_s} \frac{C}{w_s} \qquad s=1,\ldots,m \tag{A-1}$$

From (23) in the text we can rewrite $\frac{\partial C}{\partial w_s}$ as

$$\frac{\partial C}{\partial w_s} = \left[\beta_s + \frac{1}{2}\sum_{t=1}^{m} B_{st}(\ln w_t - \ln \bar{w}_t) + \sum_{i=1}^{n} C_{is}(\ln \Psi_i - \ln \bar{\Psi}_i) + \sum_{p=1}^{z} F_{sp}(\ln t_p - \ln \bar{t}_p)\right] \frac{C}{w_s} \qquad s=1,\ldots,m \tag{A-2}$$

We are looking for the matrix of the second derivatives of the cost function, therefore

$$\frac{\partial^2 C}{\partial w_t \partial w_s} = \frac{1}{2} B_{st} \frac{C}{w_t w_s} + \left[\frac{\partial \ln C}{\partial \ln w_s}\right] \frac{\partial C}{\partial w_t} \frac{1}{w_s}, \quad \begin{matrix} s=1,\ldots,m \\ t=1,\ldots,m \end{matrix} \tag{A-3}$$

which can be rewritten as

$$\frac{\partial^2 C}{\partial w_t \partial w_s} = \frac{C}{w_t w_s}\left[\frac{1}{2} B_{st} + \frac{\partial \ln C}{\partial \ln w_s}\frac{\partial \ln C}{\partial \ln w_t}\right], \quad \begin{matrix} s=1,\ldots,m \\ t=1,\ldots,m \end{matrix} \tag{A-4}$$

with

$$\frac{\partial \ln C}{\partial \ln w_s} = \frac{\partial \ln C}{\partial \ln w_t} = \beta_{st} + \frac{1}{2}\sum_{t=1}^{m} B_{st}(\ln w_t - \ln \bar{w}_t) + \sum_{i=1}^{n} C_{is}(\ln \Psi_i - \ln \bar{\Psi}_i) + \sum_{p=1}^{z} F_{sp}(\ln t_p - \ln \bar{t}_p) \tag{A-5}$$

It is important to note that it is not sufficient to verify concavity for the average firm size; it has to be done for each firm within the sample.

2. Elasticity of demand of factor s with respect to technological constraint p

From the definition of elasticity, we have

$$\Theta_{sp} = \frac{\partial x_s}{\partial t_p} \frac{t_p}{x_s} \qquad \begin{matrix} s=1,\ldots,m \\ p=1,\ldots,z \end{matrix} \qquad \text{(A-6)}$$

Since $x_s = \frac{\partial C}{\partial w_s}$ (from Shephard's Lemma), then

$$x_s = \frac{\partial C}{\partial w_s} = \frac{\partial \ln C}{\partial \ln w_s} \frac{C}{w_s} \qquad s=1,\ldots,m \qquad \text{(A-7)}$$

Differentiating (23) with respect to $\ln w_s$ gives us

$$x_s = \left[\beta_s + \frac{1}{2} \sum_{t=1}^{m} B_{st}(\ln w_t - \ln \bar{w}_t) + \sum_{i=1}^{n} C_{is}(\ln \Psi_i - \ln \bar{\Psi}_i) + \sum_{p=1}^{z} F_{sp}(\ln t_p - \ln \bar{t}_p)\right] \frac{C}{w_s} \qquad s=1,\ldots,m \qquad \text{(A-8)}$$

Now, differentiating (A-8) with respect to t_p yields

$$\frac{\partial x_s}{\partial t_p} = \left[\frac{F_{sp}}{t_p} \frac{C}{w_s}\right] + \left[\left(\beta_s + \frac{1}{2} \sum_{t=1}^{m} B_{st}(\ln w_t - \ln \bar{w}_t) + \sum_{i=1}^{n} C_{is}(\ln \Psi_i - \ln \bar{\Psi}_i) + \sum_{p=1}^{z} F_{sp}(\ln t_p - \ln \bar{t}_p)\right) \frac{\partial C}{\partial t_p} \frac{1}{w_s}\right] \qquad \begin{matrix} s=1,\ldots,m \\ p=1,\ldots,z \end{matrix} \qquad \text{(A-9)}$$

Moreover, since $\frac{\partial C}{\partial t_p} = \frac{\partial \ln C}{\partial \ln t_p} \frac{C}{t_p}$, we may substitute this for $\frac{\partial C}{\partial t_p}$ in (A-9) which gives

$$\frac{\partial x_s}{\partial t_p} = \left[\frac{F_{sp}}{t_p}\frac{C}{w_s}\right] + \Big[(\beta_s + \frac{1}{2}\sum_{t=1}^{m} B_{st}(\ln w_t - \ln \bar{w}_t) + \sum_{i=1}^{n} C_{is}(\ln \psi_i - \ln \bar{\psi}_i)$$

$$+ \sum_{p=1}^{z} F_{sp}(\ln t_p - \ln \bar{t}_p))(\gamma_p + \frac{1}{2}\sum_{p=1}^{z} D_{pv}(\ln t_v - \ln \bar{t}_v) \qquad \text{(A-10)}$$

$$+ \sum_{i=1}^{n} E_{ip}(\ln \psi_i - \ln \bar{\psi}_i) + \sum_{s=1}^{m} F_{sp}(\ln w_s - \ln \bar{w}_s))\frac{C}{t_p\, w_s}\Big] \quad \begin{matrix} s=1,\ldots,m \\ p=1,\ldots,z \end{matrix}$$

Multiplying (A-10) by $\frac{t_p}{x_s}$ we find the following expression for Θ_{sp} evaluates at $w=\bar{w}$, $\psi=\bar{\psi}$ and $t=\bar{t}$

$$\Theta_{sp} = \frac{\partial x_s}{\partial t_p}\frac{t_p}{x_s} = F_{sp}\frac{C}{w_s\, x_s} + \beta_s\,\gamma_p\frac{C}{w_s\, x_s} \qquad \begin{matrix} s=1,\ldots,m \\ p=1,\ldots,z \end{matrix} \qquad \text{(A-11)}$$

Since we are evaluating Θ_{sp} at the average firm size, we must substitute into (A-11) the average fitted factors share, that is

$$\frac{w_s\, x_s}{C} = \beta_s \text{ (at } w=\bar{w},\ \psi=\bar{\psi} \text{ and } t=\bar{t}) \qquad s=1,\ldots,m \qquad \text{(A-12)}$$

Substituting (A-12) into (A-11) gives us the following expression for Θ_{sp}:

$$\Theta_{sp} = \frac{F_{sp}}{\beta_s} + \gamma_p \qquad \begin{matrix} s=1,\ldots,m \\ p=1,\ldots,z \end{matrix} \qquad \text{(A-13)}$$

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